TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF

AUSTRALASIA.

Vol. I. Part VI.

EDITED BY

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GEOLOGICAL SOCIETY OF AUSTRALASIA, 45 Queen Street.

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THE CAUSE OF THE ICE AGE AND OF GEOLOGICAL CLIMATES.

By MARSDEN MANSON, C.E.

(*Read May 30th*, 1892.)

"The most important problem in terrestrial physics . . . and the one which will ultimately prove the most far reaching in its consequences, is: What are the physical causes which led to the Glacial Epoch* and to all those great secular changes of climate which are known to have taken place during Geological Ages?" (*Dr. Croll, Climate and Cosmology*).

SINCE Agassiz announced the past existence of an age during which ice covered temperate and tropical land areas, *the cause* of this wonderful phenomenon has been a problem of profound interest. Upon the correct solution of it hinges also the cause of Geological climates.

So great has been the interest attaching to this subject, that more study has been devoted to it during the past fifty years than perhaps to any other in Geology: hardly a leading scientific magazine runs through a year's numbers without one or more articles upon it; and no Geological Society is without zealous students of glacial phenomena. Some have become so absorbed in the subject that, led by the recurrence of certain slight astronomical influences, they recognise a glacial period for every boulder or bed of coarse conglomerate they discover, forgetful of the fact that an era of frigid climate could not intervene between two tropical climates without the intervention of temperate climates.

In order to account for local evidences in a faint measure resembling some known

* The writer prefers the nomenclature of Dr. Geikie and others using the term Ice Age rather than Glacial Epoch, or Period. The duration of this age was not recorded in the same manner and terms as either previous or succeeding ages; this is due to the inactivity, or even absolute suspension of the great forces, heat and moisture, over continental areas during this age; under estimates of its duration are thus liable to be made.

glacial phenomenon, the glacial enthusiast proceeds to upheave the solid crust of the earth to an elevation suitable for glaciation, and again to conveniently depress it to receive its tropical growth.

The evidences establishing the reality of the Ice Age during the Quaternary period are now beyond dispute. It is difficult, however, to establish by palæontological evidence the synchronal glaciation of all the continental areas known to have been heavily glaciated. This difficulty arises from the fact that the identity of various strata has to be established by fossils of varying conditions and characters; it is also rare that the same geologist has visited and compared the evidence upon more than two continents, thus eliminating probable errors from unequal subaerial denudation and exposure upon different continents. Again, the proof of the contemporaneous existence of corresponding strata upon different continents in the same latitude is sometimes attempted by a comparison of land fauna and flora, with marine fauna and flora, or even by more complex comparisons. Fossil plant life is by far more reliable than animal life for comparative purposes.

Another misleading factor is found in the interpretation of the great trans-continental lines of terminal moraines into the absolute limits of glaciation. Considering the enormous lapse of time since the glaciation of temperate and tropical latitudes, it is more than probable that the existing unobliterated evidences by no means mark the extreme limits of a lighter and more extended glaciation whose traces have been destroyed. It is not impossible, nor entirely improbable, that early local glaciation did not occur during the early part of the Cenozoic Era, or even earlier, but the data upon which to establish the occurrence of such early local glaciation is both meagre and obscure. Should the evidences of such early local glaciation be developed beyond dispute, they will in no way interfere with the interpretation to be given. So far as the author has been able to examine such evidence, it has been found to be between fossil life of a torrid character, with no evidences of a gradual merging into a temperate climate above and below it, as in Cenozoic glaciation.

Before entering further into this discussion, it may not be out of place to briefly review the principal theories advanced to account for the Ice Age. It will be seen that physicists and astronomers have vied with geologists in the diligence of this search for the cause of this age, and their minds have been as fertile in the number of causes assigned as the true one. Not one of all the causes suggested has been sustained by argument without a flaw in the reasoning, and no demonstration has been made which has carried conviction to the scientific world.

It would not be instructive to attempt to review all of the theories which have been urged. The leading ones only will be briefly mentioned.

In a recent monograph on the subject, the following are given: *

(1). A decrease in the original heat of the globe.

(2). Changes in the elevation of land, and consequent variations in the distribution of land and water.

(3). Changes in the obliquity of the axis of the earth.

(4). A period of greater moisture in the atmosphere.

(5). A variation in the amount of heat radiated by the sun.

(6). A variation in the heat absorbing power of the sun's atmosphere.

(7). Variations in the temperature of space.

(8). A coincidence of an Aphelion winter with a period of maximum eccentricity of the earth's orbit.

(9). A combination of (8) and (2).

To which may be added:

(10). The views of Sir Robert Ball, LL.D., &c., as expressed in his recent work, *The Cause of an Ice Age.* The main part of this is a demonstration to the effect that 63 per cent. of solar heat reaches the earth during summer, and the remaining 37 per cent. in winter. Nothing is added to Dr. Croll's physical theory, nor does the demonstration in any way remove the serious objections which have been urged against Dr. Croll's views.

The first of these theories is universally admitted, and taught in even elementary works on Physical Geography, but it fails to account for all the phenomena accompanying the Ice Age, or to account for the disappearance of that age, and, so far as the author is aware, has not been presented in rigid conformity with known laws.

The second has been proved to be a local and correlated phenomenon, but cannot be accepted as a *cause*, since glaciation did not solely depend in the same latitudes upon elevation above sea level.

The synchronous and wide distribution of glaciation, following an equally wide dis-

* Proceedings of the Technical Society of the Pacific Coast, Sept., 1891, Vol. viii. See also Climate and Time, Climate and Cosmology, Croll. Island Life, Alfred Russell Wallace, F.R.S., &c. Philosophical Magazine, May, 1864. British Association Reports, Part 2, p. 11. Proceedings Royal Soc., Vol. xxviii., p. 15. Quart. Jour. Geological Soc., Feb., 1878. Nature, July 4th, 1878. Trans. Geological Soc., Glasgow, Feb. 22nd, 1877. The Ice Age in North America, Dr. Fred. G. Wright, Appendix by Warren Upham. The Cause of an Ice Age, Sir Robert Ball, F.R.S., &c. Révolutions de la Mer déluges périodique, Alphonse Joseph Adhémar.

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tribution ~~to~~ torrid, then tropical and temperate climates, proves that climatic changes were brought about by secular lowering of the temperature of the whole globe.

As to the third, whilst slight changes in obliquity occur, and must continue to occur, the distribution of glacial phenomena is too general to warrant the acceptance of such change as a prime cause.

The fourth is a necessary consequence of the first, but, like the first, fails when the crucial test of accounting for the disappearance of the continental Ice Sheets is applied.

The fifth, sixth, and seventh theories are mere hypotheses, unsupported by either demonstration or observed facts.

The eighth has been presented to the scientific world through the labours and researches of that eminent geologist and physicist, Dr. James Croll, in his various articles in leading scientific magazines, and, lastly, in his grand contributions to the subject under discussion, "Climate and Time" and "Climate and Cosmology."

The ninth has been maintained by the greatest of English-speaking Naturalists, Mr. Alfred Russell Wallace. He combines the theory of Dr. Croll with that of Sir Charles Lyell, and very ably presents his views in "Island Life."

The strongest support that has been given to any of the above theories is made by the arguments and deductions of Dr. Croll and Mr. Wallace; yet they have failed to produce conviction, for, in a recent work on Geology, the author, after reviewing the various theories as to the cause of the Glacial Period, uses this expression:—"This seems to be by far the most probable yet presented."*

This opinion is directly given upon only one—the ninth; but its terms are such that it embraces all. If the ninth is "by far the most probable," it would be difficult to fix the degree of probability or improbability of the others.

The only explanation which can be accepted is one which will admit of definite proof, and will satisfy all the conditions, and not require the distortion of known facts into arbitrary moulds of its own make. It must start from universally admitted premises, and in rigid consonance with known laws, correctly interpret the grand eras of climate which have marked the geological history of our globe—aye, more, it must be so general as to be of universal force and applicable to other members of the solar system constituted as our globe.

* Elements of Geology, L~~a~~ Conte, 2nd Edition, page 578.

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In the brief review just made of the nine principal theories urged by various scientists as causes producing the Ice Age, it was remarked of the first that it was universally admitted as true, and even taught in elementary works on Physical Geography, but that it failed to account for all the facts developed by the Ice Age. This first theory was a decrease in the original heat of the globe, the truth of which is established by a mass of indisputable geological evidence.

It is also universally admitted that this original heat has been so lost that it is no longer a factor in the surface temperature of the earth, and that solar energy is now the controlling source of heat.

There can then be no mistaking the first nor the present condition of the earth as regards its exposure to the only two sources of heat—(1) solar heat, and (2) resident, internal, or earth heat.

There must, then, have been two marked eras of climatic control—(A) a past era, during which both sources were active; (B) and the present era, during which only one prevails.

Or, in other words, we have, *first*, a heated globe having resident in its mass a finite quantity of heat, undergoing loss and exposed to a single exterior source, which may be either increasing or decreasing in its energy, but so slowly that it may be considered sensibly constant; *second*, the same globe deprived of its heat to such an extent that a crust of non-conducting material has formed, the outer surface of which is exposed only to solar heat, and whose climates are entirely controlled thereby. The objects in view being to explain the occurrence of an Ice Age, and the peculiar uniformity of climates prior to the Ice Age, in strict conformity to known laws, and without departure therefrom.

At the risk of repetition we will again state that the prime objects are to demonstrate—

1. That in the passage of the earth, from an era during which its climates have been controlled by internal heat into an era during which its climates are controlled by solar heat, a Glacial Period must intervene.

2. That the direct *cause* of the *Glacial Period* was a combination of the remarkable properties, in relation to heat and cold, possessed by the various forms of water: As *vapour*, in the form of fogs and clouds it prevented the loss or receipt of heat by radiation; as *water*, by reason of its high specific heat, it retained to the last moment the effective remnant of earth heat; as *ice*, it assumed a solid form, storing the maximum amount of cold.

3. That through all geological time to the culmination of the Glacial Period solar heat was only conservative of earth heat.

During the existence of sensible quantities of earth heat the oceans must have been heated from the bottom, and cooled at the surface by evaporation. The evaporation from the total ocean surface under such conditions would give rise to much more extensive cloud formations than at present. Indeed, the record of temperatures and character of life are such as to warrant—nay, even force—the conclusion that the whole earth was one vast hothouse, from which solar heat was shut out, and throughout which a uniform temperature was prevalent from pole to pole.

Solar heat does not penetrate the thinnest cloud; even a fog through which the form of the sun is distinctly visible shuts out nearly all direct solar heat. The failure in the past to recognise the climatic influence which the factor earth heat was able to produce, and the endeavour to ascribe to solar energy the climatic conditions existing during the activity of earth heat, has caused all the mystery and error of attempts to explain the climatic phenomena during and prior to the Ice Age.

Once realise the peculiar influence and domination of earth heat, and these mysteries and errors fade, and the whole system of glacial and preglacial climates becomes simple.

The function of solar heat during the activity of earth heat could be none other than conservative of the latter; such function it is now performing for the great planets, Jupiter and Saturn, and probably Uranus and Neptune, whose surfaces are shrouded from our view by clouds.

In reviewing the temperatures recorded by the fossil life of the Paleozoic era, the fact becomes apparent that nowhere upon the surface of the globe during that era were there any zones of temperature. The whole surface was subjected to one universal torrid climate—the life developed was uniform in its general character from the Arctic to the Antarctic circle. Under no possible conditions could such uniformity of climate have been established and controlled by solar heat alone. Hence during this period earth heat was the controlling source.

The palæontological evidence of the Mesozoic and Cenozoic eras is equally convincing as to the perfectly uniform tropical climate of the one and the temperate and later frigid climates of the other.

When we examine the evidence found in one of the present climatic zones, this change of climate from an ultra-torrid successively to a torrid, tropical, temperate, and, lastly, frigid character, is not only very marked, but is everywhere the same.

Upon the establishment of solar heat in the control of surface temperatures, we find the isotherms entirely at variance with those ante-dating the Ice Age. We find also

strong corroboration in the lines of retreat of the continental ice cap. These lines are sensibly parallel with the isotherms established by solar heat.

These facts distinctly prove the totally different source and distribution of heat before and since the Ice Age. Nowhere has fossil life been developed to the extent and with the accuracy of detail as in England. Here the order of climates, as thus recorded, has been: First, torrid; second, tropical; third, temperate; fourth, frigid; and fifth, temperate. The same order is true for any portion of either temperate zone; under the equator the order of climates has been the same, except a return to tropical conditions and life.*

In the North frigid zone this same order of climates has been found, except that there has been no change from the conditions left upon the dying out of earth heat; in other words, solar energy has not removed glacial cold in those regions least exposed to its action.

The removal of glacial conditions has been less in the Antarctic than in the Arctic regions, from causes pointed out by Maury, and more fully treated by Dr. Croll. This removal has also been subjected to variations due to the mild astronomical influences ascribed by Dr. Croll as sufficient to produce glaciation.

These astronomical causes undoubtedly must have produced slight secular variations in the relative exposures of the two hemispheres to solar heat. They have not been demonstrated to be of sufficient influence to produce glaciation, and in no way could they sensibly affect climates prior to the establishment of the control of solar heat.

The distribution of heat, prior to the Ice Age, as recorded by fossil life, being entirely at variance with that now found, and being entirely independent of proximity to, or distance from, the equator, distinctly proves that climates were established and maintained independently of solar heat, and hence belong to the only other source, viz., earth heat.

It is also evident that under no possible conditions could solar energy maintain a torrid, tropical, and lastly, temperate climate over the whole range of the present zones of climates, and that this uniform distribution of heat prior to the glaciation of the globe was due to an evenly distributed supply from a constantly and uniformly decreasing source.

Moreover, the wide distribution of glaciation over the present temperate and torrid zones is a distinct proof of the exclusion of solar heat from those regions during glaciation; the great continental lines of glacial retreat being sensibly parallel with existing

* See Geological Sketches, Agassiz, p. 154 *et seq.* Also Physical Geography and Geology of Brazil, Prof. Ch. Fred. Hartt, pp. 22, 28, 29, 217, 469, 470.

isotherms, prove solar energy to have been the sole cause of glacial removal. Glacial dispersion followed one of two general laws:—First, the great centres or belts from which dispersion took place in apparent disregard of the slope of the ground were from areas most exposed to cyclonic activity and resulting precipitation. Second, minor centres of dispersion (or local glacial dispersion) were from elevated lands, subjected to uniform precipitation.*

The outline thus given is capable of demonstration, in perfect consonance with known physical laws. Such demonstration was first given by the author in September, 1891, and is reproduced here slightly modified and extended, from Vol. VIII. of the Proceedings of the Technical Society of the Pacific Coast.

THE GENERAL PROPOSITION.†

GIVEN.—A heated globe, constituted and circumstanced as the earth, and whose surface temperatures, by reason of internal heat, are above the boiling point of water, to prove that before its surface temperatures can pass under the control of solar heat, the continental areas ‡ must be glaciated.

It will be observed that the surface temperatures of a globe thus situated are entirely

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* See Proceedings Technical Soc. Pacific Coast, Vol. VIII. No. 1, June, 1891, Physical and Geological Traces of Permanent Cyclone Belts. To those interested in a verification of this very wide distribution of glaciation, the following short list of authorities is recommended :

Europe and Asia.—The Great Ice Age (Giekie); Note on the Glaciation of parts of the Valleys of Jhelan and Scind Rivers in the Himalaya Mountains of Kashmere, L at 34° N, (Capt. A. W. Sleff, F.G.S.; Jour. Geol. Soc., London, Vol. XLVI. p. 66; Mem. Geol. Survey of India, Vol. XXII., also Vol. XIV.; Record Geol. Survey of India, Nov., 1880; Jour. Asiatic Society, Bengal, XXXVI. p. 113; Brit. Association Report, 1880. The European Glacial Literature is too extensive to mention.

America.—The Ice Age in North America (Wright); U. S. Geological Reports; State Geological Reports of Ohio, Kentucky, Pa., New York, Minnesota, Nebraska, Colorado, Illinois, &c.; Virginia Am. Jour. Sci., Vol. VI. p. 371; California Am. Jour. Sci., Vol. III. p. 325, Vol. X. p. 26.

South America.—Geological Sketches, Agassiz, p. 154, et seq.; Geol. and Physical Geog. of Brazil (Prof. Ch. Fred. Hartt), pp. 22, 28-9, 469-70, 490, 558.

Africa.—Geol. of South ~~America~~ (Stow); Quart. Journ. Geol. Soc., London, Vols. 17 and 18.

Australia.—Climate and Time (Croll), p. 295; Am. Jour. Sci., Vol. 32, third Series, p. 224; Proc. Linnæan Soc., N.S.W., May, 1886.

† The proposition here stated is applicable to any planet. It is probable that Mars, Venus, and Mercury have passed through periods corresponding to our Ice Age, and that Jupiter, Saturn, Uranus, and Neptune have not reached theirs. A study of Jupiter in this connexion is particularly instructive. Phenomena are presented which are easily explained by the theory under discussion. See Zenographic Fragments, London, 1891.

‡ There were circumstances protecting certain areas, such as the "Unglaciated Area," in the basin of the Yellowstone River, in North America. Here vast and continuous lava overflows in Wyoming, Idaho, Oregon, and Washington, liberated earth heat; which heat, borne easterly by the general circulation of the atmosphere, caused the precipitation upon the "Unglaciated Area" to be warm rains instead of snow. To this region the animals of the tertiary period retreated as glacial conditions surrounded them. Here they were protected, and perpetuated their species, and in these regions vast quantities of their remains are found.

The easterly projection of the unglaciated area is opposite the corresponding projection in the lava overflow. How this simple explanation has escaped the researches of geologists is not known.

controlled by its own internal or earth heat; for between such surface and any external source, a dense cloud of vapour must exist. The fact that direct or radiant heat rays cannot pass through dense fogs and clouds is well known; therefore, a globe thus situated can neither give off, nor receive, radiant heat. The peculiar function of solar heat during the existence of appreciable quantities of earth heat was to warm the upper regions of the atmosphere exposed to its action, thus retarding the action of the cold of space in exhausting the earth heat.

By the conditions of the problem presented, we thus have a globe having resident in its mass a finite quantity of heat exposed to loss only by means of the gradual expansion of water into vapour, and the exposure of this vapour to the cold of space. This vapour would then condense, and as rain, snow, or hail descend all, or part, of the way to the earth, receive another increment of heat, and ascend as before. A slow process, but exhaustive in time.

Thus, the property of water to assume three forms, each of which possesses remarkable qualities with regard to heat and cold, afforded the only means for exhausting the earth heat. As vapour, it possesses the property of storing more heat than any other known substance; as snow or ice it possesses the property of storing more cold than any other known substance. The function of solar heat, until the exhaustion of earth heat by this process, was simply conservative; it merely warmed the upper layers of the atmosphere, through whose dense vapour its heat rays could not pass. Light rays possess greater cloud-penetrating power, and hence reached the earth earlier than heat rays.

The earth may thus be regarded as having been surrounded by a series of spheroidal isothermal shells of mean temperatures. The one next the surface represented a mean temperature of 212° + t° Far.; t being positive, and proportioned to the greater pressure of the heavier atmosphere existing. Above this isothermal shell were others representing mean temperatures of 90°, 60°, 32° Zero, etc., to x° Far., the extreme cold of interplanetary space. Between the two spheroidal iostherms of 32° and x° Far., was one which had a mean temperature of 32°–y°, and equally exposed to both sources of heat.

That the spheroidal isotherm of 32° Far. was within the sphere of influence of earth heat, is proven by the formation of snow or ice at that temperature, both being the resultant of vapour expanded and raised by earth heat to that height as a minimum. Moreover, vapour would have reached that height as a minimum were solar heat suspended for a definite period, and the earth absolutely exposed to the intense cold of space.

The isothermal shells nearest the earth were spheroidal in shape, and by reason of the conditions their surfaces were practically parallel with that of the earth; those most

remote from the earth, by reason of solar influences, protruded at the equator and flattened at the poles, so as to be slightly more oblate than the earth; they were sensibly parallel with the spheroidal isotherm now marked by the "snow line." Hence at the equator the direct action of the sun was first felt and established. As the earth heat was a finite quantity exposed to loss, it was in time exhausted. As this loss proceeded, these spheroidal isothermal shells of mean temperatures shrunk in upon the earth, and their contact with its surface marked the zones of corresponding climates prevailing during the dual source of heat. As these climates were independent of direct solar heat, they varied from the climates established by solar heat alone; hence the marked difference between climates antedating and succeeding the glacial period. The isotherms preceding this period were dependent almost entirely upon elevation above sea level, fractures and conductivity of the earth's crust; those succeeding it are dependent upon proximity to the equator, elevation above sea level, and the distribution of heat by ocean currents.

At the expiration of a period of time T., the earth lost sufficient heat to cause the isothermal shell of 90° Far. to shrink to the surface except at fractures, and a particularly uniform, moist, and highly torrid climate was established, and types of life developed, culminating in the Carboniferous Period.

The crust cooled sufficiently to permit the demarkation of the continental areas, but the cooling did not proceed to that point which unheaved the massive mountain ranges, nor greatly depressed the ocean areas. Therefore, an era of low, flat continents, and shallow hot seas followed. The life of that period abundantly shows this condition from one pole to the other, and the prevailing temperature is distinctly recorded in the fossil life of the Palæozoic Era.

Light rays reached the surface prior to this time, as evidenced by the development of visual organs in animal life. The greater part of the vapours and gases existing previously in the atmosphere were condensed, and existed upon the surface; the vapours as highly heated oceans, and the gases in various combinations of the mineral and life kingdoms. Now, in the oceans thus formed and further enlarged there was stored up a vast quantity of the original earth heat by reason of the *high specific heat of water*, from which it was not exhausted until the last moment; and in this process of exhaustion, it must have maintained the cloud shield, shutting out solar heat until the last remnant of available earth heat was exhausted. Not only this, the oceans thus formed had a mean temperature of $90° + z°$ Far., z being a positive increment due to the heat received from the bottoms and sides of the ocean. Not until the bottoms of the oceans were subjected to a degree of cold approximating that to which the continental areas were exposed could the crust be cooled uniformly and reach that degree of uniform thickness and stability suitable to the safety and comfort of the human race.

At the expiration of the period of time T, the spheroidal isothermal shell having a mean temperature of 60° Far., similarly shrunk to the surface of the earth, and a corresponding uniformly temperate climate was established.

The further cooling of the crust caused its shrinkage, and a consequent greater upheaval of those areas most exposed to loss of heat, the continents. This further shrinkage caused the strata formed during the previous eras to be upheaved and fractured, and the lines of demarkation between oceans and continents were thus more strongly accentuated.

The life developed in the interim evidences an approach to that of the present; and its wide distribution demonstrates the complete control of the climates of the globe by internal heat. The isothermal lines were entirely at variance with those established by solar heat, therefore the functions of solar heat remained conservative of those operating on the surface during this period also.

The extreme and uniform distribution of fur or hair-covered animals and of the deciduous and coniferous trees of the Cenozoic era mark further the control of a source of heat more uniformly distributed than solar heat could possibly be. For reasons previously given, this isotherm also reached continental areas earlier than ocean areas. When the mean temperature of the land was 60° the tepid oceans must have had a mean temperature of $60°+y°$ Far., y, like z, being positive, and due to increments of earth heat received from ±
the bottom.

At the expiration of this period T', or at some time, $T' + a$, the isothermal shell of 32° Far. shrunk so as to reach the more elevated portions of the continental areas, and thus established a snow line independent of the influences now establishing and maintaining such snow line. The moment a snowflake reached the earth which the waning earth heat was unable to melt, the Ice Age was inaugurated; and the conditions were such as to favour its extension until the exhaustion of the store of heat beneath the oceans and resident in them, by reason of the high specific heat of water. It will be noted here that whenever, in obedience to the expansive force of this waning earth heat, a particle of water was vaporized and made the last round of its circulation, it returned to the earth in that form which stored the maximum degree of cold, or, in other words, in that form which required the maximum amount of solar heat to change. From the moment that snow began to accumulate, every remaining vestige of earth heat was available for producing those conditions favourable to glaciation, namely warm seas, dense fogs and cold continental areas; and every unit of solar energy reaching the upper regions of the atmosphere was available for maintaining those favourable conditions.* Glaciation

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* The prime objection which is urged against all previous theories is their inadequacy. We here have a perfectly adequate cause—resident earth heat to supply evaporation and shut out solar energy, which energy can only act the part of a conservator of the glacial conditions until the exhaustion of earth heat, when its power can be spent in melting glacial ice, and in gradually establishing the present conditions.

under these conditions would be cumulative until the oceans, exhausted of their heat and lessened in area, were no longer able to supply the moisture necessary to completely shroud the earth from direct solar heat.

At the expiration of the time T″, the isothermal shell, having a mean temperature of 32° Far., shrunk in upon the globe, and the oceans were exhausted of their store of heat and their bottoms brought in contact with water having a mean temperature of 31° Far., a temperature approximating that of the ocean depths at present, and of ice in masses.

The isothermal shell 32° Far. having been spheroidal in shape but more flattened in the prolongation of the axis of the earth than the earth itself, reached polar land areas prior to reaching equatorial land areas, and by reason of the high specific heat of water, reached continental areas prior to reaching ocean areas. The crust beneath the ocean, having been protected from loss of heat by the superincumbent water, shrunk to its final shape subsequent to that portion forming continental areas. The ocean bottoms in thus shrinking approximately to their present shape must have been fractured, as continental areas had previously been. In this way very considerable increments of earth heat were set free after glaciation had commenced. This process, which is entirely in consonance with known laws, would result in increasing the depth of glaciation, or even in re-establishing it after partial recedence. There would also result a complicated series of crust movements as the continents were relieved of pressure by the melting of the ice caps, and the ocean bottoms subjected to increased pressure by the restoration of water to the oceans.

Thus the same forces which, even before the eras we have been considering, must have built up upon the surface of the globe mineral forms of surpassing beauty, only to be destroyed and ground down to give place to vegetable and animal forms of wonderful development—these same forces were called upon to well nigh obliterate every living individual of both kingdoms. The efficiency of their work is attested in every zone of life from the equator to the poles.

The exhaustion of the residuum of earth heat in the oceans and beneath them could only have been accomplished by the same means as before, and this exhaustion resulted in the preservation of those conditions most favourable to glaciation. When by the chilling of the oceans to about 31° Far. and by the glaciation of continental areas, the air was cleared of obscuring clouds and fogs, the wonderfully uniform series of climates was at an end.

With the dominion of solar heat began seasons of spring, summer, autumn and winter, with the varying changes of the earth's annual round.

The climatic changes during the control of earth heat extended over eras:—

(1). An era of torrid heat.

(2). An era of tropical heat.

(3). An era of temperate heat.

(4). An era of glacial cold.

Each merged gradually into the others, but each recorded its period of existence in unmistakable terms, all shrouded from the direct action of solar heat, and all evidencing by the life produced, the stifling, smothered character of the climate.

That solar heat was shut out from the surface of the earth during the Glacial Period is geologically recorded in the glaciation of the North Temperate Zone over continental areas, where solar energy has removed glacial cold and established in its stead a mean annual temperature of 40° Far., and in the torrid zone it has removed glacial cold and established a mean annual temperature of 76° Far., where snow never falls.

Consequently, in a heated globe, constituted and circumstanced as the earth, exposed to two sources of heat, internal heat and solar heat, before its climates or surface temperatures can pass under the control of solar heat, the continental areas must be glaciated.

An Explanation of Geological Climates.

The dawn of the Archæan Era found the earth a heated globe merging from an unrecorded and unfathomable area of greater heat. The crystalline character of the earliest rocks demonstrates the high temperature which prevailed upon the surface at that time. Such being the temperature of the surface, it is beyond question that the existence of uncombined water upon it was an impossibility, and as vapour it could only shroud the earth in dense clouds. The earth heat was as effectually shut *in* from loss by radiation as was solar heat shut *out* from reaching the surface.

As this finite amount of earth heat could only escape by doing *work* in the expanding of water to vapour, vast eras of time must elapse before the work done could exhaust the available heat. The process of exhaustion was further retarded by two causes: 1st, the heating of the outer layers of the atmosphere by solar heat; and 2nd, the low conductivity of the strata of the earth itself; consequently the climates of the earth, until the final exhaustion of earth heat, were of remarkable uniformity. The faults and fractures of its crust set free additional increments of heat but slowly, so that the torrid, tropical and temperate eras were each longer than the frigid era. It is not improbable that upon certain of the oldest and highest mountains, glaciation was inaugurated during the early part of the Cenozoic Era, to slowly disappear by the

denudations

gradual setting free of earth heat by vast fractures of the crust. Recurrences of these fractures and submarine fractures after glaciation had commenced, readily account for the "Interglacial Periods," which were probably local phenomena antedating the close of the Ice Age. It is neither logical nor reasonable to interpret the finding of evidences of early local glaciation into a Glacial Period, for glaciations are found now in the Alps and upon certain peaks of the Sierra Nevada, and even in the torrid zone, but they by no means establish the present existence of a Glacial Period.

Once realise that the surface temperatures of the globe were at one era in the past too high by reason of *internal heat* to permit water to remain upon the surface, and the peculiar properties possessed by the various forms of water and their relations to heat and cold, and follow out these facts to their natural and logical conclusion, and the whole mystery of geological climates clears up and becomes simple.

Climatic Facts Established by Fossil Life.

It would be impossible, in the limits to which it is necessary to restrict this paper, to review the vast array of facts which could be brought forward to demonstrate the perfectly uniform, torrid character of the climates of the globe during the Paleozoic Era.

From the 75th degree of north latitude through every range of present climates to the confines of the south frigid zone, the life systems attest the stifling hot-house character of the heat. The species of plant life and animal life, whether of land or marine forms, varied less from the torrid to the frigid zones than corresponding species upon different continents in the same zone do now. Nowhere below the Permian deposits can fossil life be recognised that does not belong to an ultra-tropical type. Such uniformity of temperature is impossible under solar control, and hence can only belong to a climate controlled by earth heat.

This era merged gradually into the Mesozoic era of tropical heat, during which the forms of life developed into higher types, and their range of distribution demonstrates the still perfect control of earth heat. One peculiar and significant fact is recognisable in comparing the land forms with the marine forms of life. The former developed types more suitable to tropical climates, while the latter held more tenaciously to the torrid types, thus proving the more rapid loss of heat by the continents.

The fossil life of the Cenozoic era corroborates to a remarkable degree the still perfect control of earth heat. Throughout Greenland, Iceland, Lapland, and Spitzbergen a perfectly uniform and temperate climate existed. The magnolia of the lower Mississippi valley flourished in those localities in which, during the Paleozoic era, only the gigantic ferns *Lycopods* and *Calamites* could be found, and where now only a stunted Arctic growth can exist.

During this era identical types of life existed in all parts of Europe, Asia, and America, and a uniformly temperate climate prevailed over the whole northern hemisphere entirely at variance with the extreme range of temperatures now embraced in that half of the globe.

The control of the waning earth heat was simply dying out, and had reached that stage in which it was no longer able to maintain the high temperatures of previous eras.

Again does the high specific heat of water assert itself, for alongside of these forms are marine fossils indicative of a higher temperature.

The evidence of the high specific heat of water held the last available remnant of earth heat, and thus perpetuated its control of climates, is beyond dispute, as presented by the conditions culminating in the Ice Age.

Whatever may be the doubts as to the actual date of the Ice Age, there is no disputing the fact that the evidences establishing the culmination of that Age are found *above* or since the Tertiary, and *below* or before the Modern Era.

Between these two periods there is abundant evidence from every climate, from every zone of present life, that the continents were glaciated.

Europe and Asia, North and South America, Africa and Australia, all present glacial striæ, boulder deposits, and other marked evidences of glaciation at the same period, just antedating the Modern Era, or during the Quaternary Period.

The ascription of great elevations above sea level during the Ice Age is natural, and such apparent greater elevation is due to *two* causes during this period, whilst due to only *one* cause during previous eras. As the surface of the earth became subjected to a temperature of 31° Fahr. under the oceans, and a corresponding temperature under the continental ice caps, contraction and consequent elevation was continued as before; and as snow was piled up upon the continents, water was withdrawn from the oceans; for each million square miles of continental ice cap three hundred feet thick a corresponding three million square miles of ocean was lowered one hundred feet. The continental ice caps already approximately known were too vast not to have lowered the sea level to a marked degree.

The apparent depression after the Ice Age is as easily explained. By the melting of the greater portion of the ice caps, and the evaporation of vast inland seas, the sea was approximately restored to the level existing prior to the Ice Age, thus causing an apparent sinking of the land.

The great difference between climatic conditions prior to and since the Ice Age is

very marked around inland seas and basins without drainage. Lake Bonneville and Lake Lahontan, in the United States, and the greater area once occupied by the Caspian and other seas, evidence the superior dampness and rainfall antedating the Ice Age. During the control of earth heat the oceans were heated to their bottoms, and furnished moisture enough to keep these great depressions full of water and to support a dense life upon now desert areas. The dry air of the modern era has not only absorbed the water in these vast lakes, and restored it to the oceans, but vast areas have been converted into deserts by the unequal distribution of heat and moisture under solar control.

Thus the Ice Age marks the date at which the climates of the globe passed from the control of earth heat to that of solar heat. The great specific heat of water retained in the oceans the energy necessary to maintain the cloud shield shutting out solar heat until both land and ocean areas could be equally cooled and contracted, thus ensuring the maximum degree of stability to the crust. The mysteries of geological climates develop thus into a system beautiful in its simplicity.

THE GEOLOGY OF THE IRON ORES OF MINNESOTA, U.S.A.

By N. H. WINCHELL, State Geologist, Minneapolis, Minn.

(Read May 30th, 1892.)

The first product of iron ore by any of the mines in the State of Minnesota was issued in 1884, when 62,124 tons (long) were produced. The next year the shipment amounted to 225,484 tons, in 1889 it was 844,638 tons, and 1891 894,281 tons. In the year 1892 it is likely to exceed 1,000,000 tons. There probably never was, in any iron region of the world, so rapid and well sustained an increase in the product of iron as has been exhibited by Minnesota during the last eight years. The country where this development has taken place was a wilderness, wholly uninhabited and largely unsurveyed in 1884, distant from settlement about one hundred miles, and from the inhospitable north shore of Lake Superior, still further north, about seventy miles. Therefore every appliance for transportation, as well as mining, had necessarily to be provided for—not to speak of all the accompaniments of civilised habitation for the mining communities that were established. It was a herculean enterprise, and its accomplishment has borne testimony to the diversified capabilities of American skill and pluck. The vastness of the plans that have been carried out, and the quiet, business-like processes which have characterised them, show at once the confidence of the promoters of the enterprise, and the reliance they placed on the integrity of American commercial securities. Before a ton of ore was shipped two and a half millions of dollars had been expended in preparations. This involved the construction of a first-class railroad, with its equipment, a distance of sixty-eight miles, over which to convey the contemplated product of the mines to the nearest available harbour on Lake Superior. In 1889 the whole plant was transferred to new owners at a stated consideration of about eight millions of dollars, after the total product of ore had reached 2,347,057 tons. This transfer also included the undeveloped lands which the State of Minnesota had granted to the original corporation to aid in constructing the railroad. These lands aggregated

616,320 acres, exclusive of the "right of way" through the country. The latter covered a strip 100 feet wide, and amounted to 1167 acres.

Age of the Minnesota Ores.

The ores, so far as developed, are of Archæan age. The Archæan is sharply separated from the overlying Taconic strata by a widespread non-conformity. The Archæan is divided into three parts—viz., in descending order:—

Keewatin.
Vermilion.
Laurentian.

The Keewatin, in which the ores thus far exploited are found, consists of sericitic and chloritic schists, passing to massive "greenstones." Throughout the most of the Keewatin a sedimentary structure is plainly visible. It fails in some of the greenstones. The greenstones vary, however, from chloritic schist to diabasic rocks that have the outward aspect of true plutonic masses. In these structureless parts of the greenstones appear volcanic agglomerates, these varying to conglomerates in which an evident sedimentary structure is apparent, the pebbles consisting of rocks of various kinds. In the agglomerates the boulder-like masses are rounded, and are usually of a basic rock resembling the greenstones themselves. There are, however, rare boulder-like masses of reddish granite found in much of this agglomerate, the existence of which has been supposed to demonstrate the prior existence of granitic land from which they could have been derived, and the late submergence of which brought about a non-conformable stratigraphic succession to the rock containing these acidic masses. In such a view this greenstone agglomerate has been considered a true conglomerate, and the names "Ogishke conglomerate" and "lower slate conglomerate" have been employed to designate it. But it seems to be reasonable to ascribe such acid rock fragments to the same agency as the basic. In the field there has not yet been found any way to discriminate between those parts of the "Ogishke conglomerate" which contain acid rock masses and those which do not. The distribution of the granitic masses seems to be entirely fortuitous. They are more frequent in some places, all other conditions being the same, than they are in others. It is plainly necessary to ascribe the basic masses to volcanic agency, the masses having been ejected as bombs, accompanied by volumes of volcanic cinder and ash, and having fallen into the adjacent sea. While naturally the large amount of such ejections would be of a basic character, there would be great probability that some of the ejected fragments may have been torn from the sides of the ducts through which the material found escape. Such ducts necessarily must have consisted, through at least a part of their course, of acidic rocks—viz., the Laurentian granites and gneisses that were formed before this volcanic age. These Laurentian gneisses must have formed the enclosing rock mouth of the earth, and through them all these basic eruptions must have passed. What wonder if these basic emissions should occasionally involve fragments of this acidic casing? It would be more wonderful if they did not.

While, however, the Keewatin is made up largely of materials that had a volcanic origin, it manifests, with even greater certainty, a structure that can be attributed only to oceanic sedimentation. To what extent this oceanic agency will have to be allowed in the formation of the greenstones, which are apparently massive or structureless, is at present a problematic and unsolved question. If the whole region was under water during Keewatin time, excepting only the immediate areas of the volcanic craters, it seems difficult to exclude, under any plausible physical hypothesis, the action of oceanic water on the great bulk of the ejections. There may have been extremely limited surface exposures where lava of Keewatin age may have congealed, in situations too elevated for the action of the ocean to affect it; and some of the greenstones which now form the surface rocks may have solidified at considerable depths below the surface without having encountered directly the action of atmospheric waters. The former would probably have disappeared long before the present, either by erosion in pre-Taconic times or in glacial and recent time. Moreover, none such have ever been seen in Minnesota belonging to Keewatin age. Such surface-cooled lavas and scoriæ have definite and marked characteristics by which they can be distinguished from rock-masses congealed at a depth below the surface, without access to atmospheric air. They are abundantly represented in the later stages of the Taconic in Minnesota, and can thus easily be compared with the basic rocks of Keewatin. As to those portions of the Keewatin greenstones which, as above suggested, may have had a hypothetical origin by solidification at considerable depths below the surface of the earth, which is the favourite hypothesis of many microscopical geologists, they exhibit certain characters which are incompatible with such deep-seated solidification.

1. They grade into agglomerates, and the agglomerates grade into conglomerates.

2. They grade into chloritic schists and sericitic schists, without assignable limits to either, and these schists, aside from their schistosity, show the plainest sedimentary structure.

3. They nearly all exhibit that structure which has been ascribed by some to "dynamic metamorphism."

4. They seldom or never show a perfect "diabasic structure," which is a microscopic character of true plutonic rocks.

5. These problematic greenstones are the carriers of the hematite ores that are mined in Minnesota, and these ores are the result of oceanic chemical precipitation.

6. On weathered surfaces, under favourable circumstances, an unmistakable sedimentary banding can sometimes be seen intersecting the most massive and apparently structureless portions of this rock.

Therefore, it may at present be left unsettled whether the most massive of these greenstones can be attributed to oceanic consolidation of fragmental eruptive matter. That the most of the greenstones are due to such consolidation there is no question, in the

writer's opinion. The lesson that may be drawn from the consolidated eruptive ash of more recent date, as seen in the western portions of the United States, where it constitutes rock-masses, hundreds, or more probably, thousands, of feet in thickness, having a regularly stratified arrangement which extends over large areas unbroken, would warrant the assumption of such origin for these basic rocks. In that case it is reasonable to suppose, also, that the degradational change which microscopical examination reveals in these greenstones may not have been caused entirely by the "dynamic" forces that have acted on them since their consolidation, but by the oceanic levigation which the constituent materials suffered in the process of sedimentation prior to consolidation. For instance, it is a common character in these rocks that they rarely or never contain augite in its pristine condition. It is changed to hornblende, and the hornblende grains are a step advanced towards chlorite; biotite is passing to a hydrous mica; menaccanite is partially or wholly changed to leucoxene; the feldspars are clouded by decay. In short, an incipient decay is apparent in all the original minerals composing the rock. Such an incipient change is one which is attributable to ordinary weathering. Such changes are well known superficial consequences in eruptive basic rocks on long exposure to the air. When they are seen to pervade a rock to its inmost recesses, even to the depth of several hundred feet below the natural surface, it is reasonable to attribute the effect in general to the same cause. It is unreasonable, however, to expect to find ordinary surface exposure of a massive rock in a region where the latest glacial agents have scoured off all the loose decayed portions, extending its effects to such depth. It appears, therefore, that this "dynamic metamorphism," on which some geologists have depended, through which to point out the original condition of these rocks, in the light of various other considerations, indicates the exact opposite, and reveals that each individual grain of the now massive greenstone, has been long weathered prior to consolidation in its present condition. This could have been effected, plainly, only by the action of oceanic waters.

It has already been remarked that the hematites of the region are carried in these massive greenstones. The circumstances which attended the formation of one must have accompanied that of the other, *i.e.*, whether eruptive or sedimentary. That the ores were deposited from chemical solution there is every reason to suppose. They have the banding characteristic of sedimentation. They constitute jaspers (or jaspilytes), in which the sole ingredients are iron oxide and silica. Ordinary sedimentation could not form such a rock. These ore bodies lie in the greenstones in the form of lenses of varying sizes, sometimes a mile in length, sometimes not more than a few rods or feet. In finely disseminated condition the same kind of silica is distributed sometimes through adjacent portions of the greenstone, or lies in thin irregular sheets interstratified with it. They are linked inseparably under the same methods of deposition. This requires, again, that the greenstone be an oceanic product; at least, as to its present structure. There is, therefore, but little excuse for appealing to any other agent than the Keewatin ocean for the structural characteristics of the Keewatin rocks, even the most massive of the greenstones.

Below the Keewatin rocks, which have a measured thickness of several miles, are the rocks of the Vermilion series. These differ from the Keewatin rocks in being entirely freshly crystalline. They show that surface weathering in northern Minnesota has not been sufficient to convert them, even superficially, to the semi-decayed state in which the Keewatin rocks are found. Fundamentally, they embrace the same minerals. They are mica schists, hornblende schists, and dark hornblendic gneisses. In some parts are extensive masses of diabasic rock, resembling that which in the Keewatin is known as "greenstone;" but in the Vermilion there is a more perfect crystallization, and apparently a greater proportion of hornblende. In many places the transition from the Keewatin to the Vermilion has been examined. There is no unconformity; there is simply a gradual transition in the crystalline condition of the constituent minerals. Quartz, which is abundant in both in fragmental grains, causes, by its varying amount, a regular and unmistakable sedimentary banding, indicating both formations, the action of oceanic distribution in the arrangement of the materials. The lowest part of the Archæan is the Laurentian. This is gneissic, and where the passage from one to the other can be seen in its normal condition, the Vermilion also grades imperceptibly into the Laurentian by the acquirement of a greater per centum of silica. But this conformable passage from one to the other is not, perhaps, the most usual manner of transition. There appears to be great irregularity; the strata are broken as by eruption. Large masses of the Laurentian are brought into non-conformable relations with the Vermilion schists, and while in a plastic condition they have been made to enter fissures in the darker schists, and to embrace isolated portions of them. Associated with this disturbed condition in the acid Laurentian appear also large areas of basic irruptive rock. This also penetrates the adjoining beds, and indicates the contemporaneous invasion of these sedimentary strata by molten rock from the deep-seated interior of the earth, at least, from below the acid super-crust. In the Laurentian, as well as in the Vermilion and Keewatin, are vast conglomeratic strata or patches. They all had primarily the same origin, viz., volcanic action. The isolated exotic masses, which even in the most completely re-constructed portions of the Laurentian, are conspicuous by reason of their contrasting colours, were hurled from the craters of early volcanoes, and were usually of basic types of rock, and remain basic yet. They constituted agglomerates rather than conglomerates, although it cannot be questioned that, in rare instances, such agglomerates through the assorting selection of currents, and perhaps of beach action, were transformed into true conglomerates.

It is plain, therefore, that the Archæan age, during which were formed the rocks latterly embraced under the term, "fundamental complex" by some United States geologists, was one of intense volcanic activity and of collision between the internal forces of heat and the external forces of refrigeration. The wavering line of battle, which has now been driven to considerable depths below the earth's surface, by the all-enveloping onset of the atmosphere was then located near the earth's surface, and the conflict was such that the debris of both contestants lies thick along the line of retreat. As the atmospheric forces,

however, permanently occupied the ground, all these records have been given the characteristic stamp of the hand of the ocean.

The Ores Themselves.

After this brief sketch of the Archæan, it will be easier to understand the characteristics of the Archæan iron ores. Although later discoveries in Minnesota denote that iron ores of Taconic age will soon be brought into commercial importance, perhaps exceeding those of the Archæan, we shall here confine our statements to the Archæan ores.

These ores in their normal condition consist of hematite. Later-formed limonite, and some pyrite, are sometimes associated, the latter more frequently embraced in the adjoining rock. Martite is also found disseminated through some of the adjoining green schists, this being an original mineral and not a pseudomorph after magnetite. Rarely, also, at some distance from the ore bodies that are exploited, narrow belts of magnetic schists are met with. These disturb the magnetic needle, whereas the great ore masses that are mined have no perceptible effect on the needle. As a mineral this magnetite must have a cause distinct from that of the large masses of hematite. It is, perhaps, due to concentration along a plane of greater pressure accompanied by shearing.

Everywhere the ore masses, and the entire structure of the rocks embracing them, stand about vertical. The laminæ of the ore itself are curved in many and tortuous directions within the ore masses. The layers of pure hematite alternate with layers of red or purple jasper or white silica, from a mere film to two or three inches in thickness, producing a vividly ribboned hard surface, on which the glacial etchings are beautifully displayed. The best ore masses, of course, are free, or nearly, from this jasper and silica, but in every case the silica and hematite are intimately intermingled. Silica is the chief impurity of the ore; it exists in minutely fine grains; it is coeval with the hematite, and not the result of substitution for some other mineral. The hematite is also an original ingredient, and is not the result of substitution for some other mineral—as, for instance, suggested by some geologists, for carbonate of lime or carbonate of iron. It will not be possible at this place to enumerate the reasons for these statements. They are based on examinations made in the field and in the laboratory. Usually the ore bodies are abruptly separated from the rock of the country. There is the merest film of "contact matter" between the greenstone and the jaspilyte. It would hence appear that the forces that supplied the greenstone were suddenly suspended for a short time, and that after the action of some force that could supply the elements of the jaspilyte, there was a renewed activity of the force or forces that formed the greenstone. This is the most frequent manner of succession; but, fortunately, it is not without exceptions, for the exceptions throw light on the relations existing between the two sorts of forces, and on the conditions that obstructed one or the other. It is largely by the study of these that the origin and

age of these ores have been established. Some of the most important of these exceptions to the abrupt transition from the ore to the country rock may be mentioned. By the term ***ore*** here is meant the jaspilyte rock, which shows all degrees of purity and interchange between hematite and silica, the two elements being microscopically mixed. By the term ***country rock*** is meant the greenstone rock which comprises the hills and entire region about the mines.

(*a.*) Rarely the greenstone element is interbanded with the jaspilyte element about the borders of the productive region, much in the manner of a sedimentary structure, which has been squeezed and rendered somewhat obscure. The sheets of each here may vary in thickness from a mere shred to layers of several inches, the greenstone increasing in a direction toward the great area of greenstone, and the silica and hematite sheets increasing toward the ore masses.

(*b.*) The jaspilyte element is sometimes distributed in pebbles through considerable areas of the greenstone, and these pebbles, originally roundish, are seen to have been subjected, along with the matrix which holds them, to a shearing movement with great pressure, producing a pseudo-plasticity, which has allowed them to be elongated in a direction parallel with the schistose direction of the region. In other places these pebbles have been accumulated in layers that are but sparcely supplied with the elements of the greenstone, constituting conglomerates; and on close inspection it has been observed that a minutely fine granular condition of this silica is disseminated through much of the greenstone, at least at points further removed from the mines, giving the greenstone, though still massive and structureless, a lighter colour and a firmer texture.

(*c.*) There are also instances in which the jaspilyte, as such, gradually fades out into a hard massive greenstone by the acquirement of the green minerals (mainly chlorite) which characterise the latter, there being in this case an entire loss of sedimentary banding which usually marks the jaspilyte.

(*d.*) Probably the most convincing fact, tending to show the identity of the forces that distributed the jaspilyte and the greenstone, is the very rare occurrence of a siliceous layer of the greenstone *within a mass of the jaspilyte*, the greenstone (or green schist) sheet following all the tortuosities of the crumpled jaspilyte. In such a case there may also be, immediately adjoining, some thin sheets of pure hematite conformably bent within the jaspilyte.

There are numerous other physical characters that throw light on the nature of the forces that operated, in Keewatin time, to originate these rocks, viz.:

1. The jaspilyte was rent asunder while being formed, and was again cemented *in situ* by fresh depositions of the elements of the jaspilyte.

2. The jaspilyte, after being rent by some force, was transported mechanically in

large and small masses, and deposited in regions where otherwise, normally, only the greenstone was being formed. Thus it occurs in angular brecciated pieces isolated in the greenstone.

3. The greenstone, while being formed, was also broken up and transported mechanically and deposited in rounded or angular masses among the layers which otherwise, normally, were being constituted of silica and hematite in regular and beautiful alternation. It is probably owing to the frailty of the greenstone or green schist that this phenomenon is but rarely seen, since such disrupted masses would be likely to be re-wrought by the disintegrating action of the transporting forces and the redistribution of the finer debris.

These considerations bear on the explanation of the structures that are to be seen by the field geologist. There are microscopic and chemical considerations, derivable from a study of the ores and the rocks in the laboratory, which are almost equally important in any attempt to make out the characteristics, and especially the origin and age, of the ore itself. It is not necessary to dwell on them here, suffice it to say that as a grand result of all the recent studies made on these ores, by the Minnesota geologists, the following conclusions have been reached:

1. The rocks are of volcanic, and but rarely plutonic, origin.

2. The ejectamenta were deposited in a surrounding sea which gave them almost universally a stratified structure. As the least evidently stratified rock masses embraced the most evidently stratified jaspilyte masses, it is presumed that the ocean was constantly present and that the sedimentary structure is lacking in the former, occasionally only by reason of some exceptional conditions — such, perhaps, as too rapid accumulation — and that everywhere the oceanic waters played their usual *rôle* in giving the volcanic fragmentals the more or less evident stamp of Neptune. These rocks were deposited, consolidated and upheaved to verticality in Archæan time.

3. While these basic accumulations were being made, the ocean's waters became alkaline, heated, rapidly transported by currents and counter currents, in places evaporated by greater heat, and in others cooled by passing beyond the theatre of disturbance.

4. In this condition they not only attacked powerfully the minerals of the volcanic debris, but they penetrated and affected more or less those which they were not able to disintegrate entirely, probably causing that semi-disintegrated state which all the minerals of the greenstones manifest to the microscopist, which has been attributed by him to "dynamic metamorphism."

5. At the same time the ocean's waters carried the soluble elements of the minerals, often in saturated amounts, away from the seat of disturbance, and such as it could hold were distributed throughout the ocean at large, to be at later geological ages precipitated

as dolomytes or limestones. Such as it could not carry away, viz., the oxides of iron and silicon, were largely deposited at once near the places where they were obtained.

6. The circumstances which caused the immediate precipitation of the oxide of iron and silicon were, (*a*) their comparative non-solubility, and (*b*) the disturbance of the balance of saturation for such elements by the volcanic actions of the time—such as acid rains, or an influx of cooler currents.

7. Thus it required the simultaneous and co-operating agencies of igneous and of aqueous forces to produce the rocks and their ores. The former supplied the material for both, but the latter received it, masticated it, re-wrought it, and distributed it. The time involved was very great, and the scene was one of the most tumultuous the earth has ever witnessed.

THE TACONIC ORES. (LOWER CAMBRIAN.)

In Minnesota ores of later date than the Archæan age have not as yet been mined in commercial amounts. They have been mined for many years in states on the south side of Lake Superior (Michigan and Wisconsin), and have supplied the best ores for making steel by the Bessemer process to the furnaces at Cleveland, Pittsburg, Buffalo, Detroit, and Chicago. Within the past year great discoveries have been made of the same ore in Minnesota. This is in accordance with, and almost a direct result of, the predictions and indications of the present geological survey of the State. It is not too much to say that, probably, there was never a more conspicuous instance of the utility of a public geological survey, or a quicker verification of its prophecies, in an economic result of such magnitude. While these ores are usually within the Bessemer limit, as to phosphorus, they do not rank as high in content of metallic iron as the ores from the Archæan. They are easily and cheaply mined. They are soft, or, at least, when not soft they are in a fragmental condition, so that they can be excavated almost without the use of any explosives. Some mysterious process of brecciation has passed over the rocks of the region, or, at least, has shattered the ores embraced in the rocks, so that they lie but little removed from their original *situs*, but broken into millions of small angular pieces. In most cases the strata dip conspicuously toward Lake Superior, whether in Wisconsin or Minnesota, and the beholder can still see, in the face of the excavation, the courses of the strata, though somewhat dislodged, as the cut edges pass across the wall.

The geological environment of these ores is quite different from that of the Archæan ores in Minnesota. These constitute strata, which extend uniformly over the region for many miles, showing the same features of dip and all the lithological characters and variations which ordinary sedimentary rocks exhibit. They unquestionably constituted originally, along with the overlying and underlying strata, constituent portions of a great sedimentary series. The prevalent idea of the origination of the ore itself within this horizon, is that which has been applied extensively to various iron ores in the United

States—viz., a substitution of iron oxide for some carbonate which pre-existed, preferably a limestone, and the concentration of ferruginous deposits from surface waters into natural troughs, through which such waters were drained. Although there is some vagueness in the statement of this idea, and still more in the idea itself, this hypothesis has a wide acceptance. Without accepting or rejecting it, at present, it will be sufficient to state that it encounters some fundamental obstacles, and that until these can be removed the theory should be held tentatively. It is not the place here to enter upon a discussion of this question.

The strata which hold the Tatonic ores of this horizon lie with marked discordance upon the Archæan. Immediately below the ore is usually a quartzyte, the bottom of the Taconic. This in some places is coarse, and made up of rounded grain, and even conglomeratic with masses of the underlying formation, whether of granite or greenstone; but in other places it is very fine grained, resembling the silica of the jaspilyte of the Keewatin. Associated with this quartzyte or calcareous strata, which sometimes are very thick, constituting marble, and at other times are wanting, the calcareous element then being mixed with the siliceous, and constituting great strata of chert, or "cherty carbonate." This quartzyte forms the foot-wall of all these ores wherever they are exploited. Overlying the ore is frequently a mass of impure ore or strata that are very siliceous, tending to become a black slate. Associated with this horizon is a great outbreak of coarse basic gabbro. This eruption overwhelmed the previously deposited strata, which sometimes also appear to have been heavily charged with pyroclastic materials from contemporary volcanoes. Still further up in the series are many successive layers of black slates and erupted sheets, the latter probably being formed by the consolidation of volcanic ash. The series finally becomes shales, sandstones, conglomerates, trap-sheets, all having a prevailingly red colour, and terminates with a fragmental red sandstone many hundreds of feet in thickness. This succession from the basic quartzyte and conglomerate to the loose red shales and sandstone at the top is not peculiar to Minnesota, but has been made out in Wisconsin, and in Michigan, in New England, Quebec, New Brunswick, and even prevails in Wales and Scotland. It is scarcely necessary to add that it is the great formation which Sedgwick designated Lower Cambrian, the equivalent of the Canadian Huronian* and the American Taconic.

MINNEAPOLIS, *March 15th*, 1892.

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* The present use of the term Huronian by the Canadian geologists is peculiar, as they apply it to a part of the underlying Archæan. It is thus entirely removed from the series of strata to which it was applied by Sir William Logan and Dr. T. Sterry Hunt. This shifting of the term, however, is only paralleled by some American geologists, who restrict the term Cambrian to the Lower Cambrian of Sedgwick, and apply the recent new term Ordovician to that horizon which Sedgwick insisted was his typical Cambrian.

NOTES ON THE LATE LANDSLIP IN THE DANDENONG RANGES, VICTORIA.

By FREDK. DANVERS POWER, F.G.S.

(Read May 30th, 1892.)

The 10th, 11th, and 12th of July, 1891, will long be remembered in Victoria as the dates on which one of the most destructive floods occurred that has taken place since that colony has been inhabited by Europeans. This unusual deluge of rain brings before us most vividly the action of disintegrating agents around us. The results of these that are most prominently brought to our notice at the S.W. portion of the Dandenong Ranges are the frequent landslips that have taken place there. These ranges run N.E. and S.W., but at the S.W. end turn towards the N.W. Landslips are by no means uncommon in this district; traces of them can be seen all along the mountain's side for about five miles in a N.E. and S.W. line. A little to the W. of the present slip one of nearly equal magnitude to the biggest just found took place in the year 1863, at which time various minor slips were also formed, including one which has lately developed into the largest of the season. When seen from a distance the main slip looks larger than it really is, as we cannot distinguish readily the talus from the slip proper, the whole forming a brick red coloured blot on the mountain side, looking like a large ploughed field. On each side of the house occupied by Mr. Sidney Ellery runs a creek. These are tributaries of the Olinda Creek, and have their sources in springs on the side of the mountain, On Sunday, 12th July, about 1.30 p.m. these creeks, which had been gradually increasing in volume and turbidness for some days, suddenly burst their bounds, and came roaring down like a river in flood, spreading out four hundred and seventy-five feet in width. This continued for some three hours, when the main slip suddenly took place, preceded by a rumbling noise, which shifted nearly an acre of land in area, and a volume equa to thirty-five thousand cubic yards, leaving a face eighty feet deep. The upper part of this slip is five hundred feet above the creek below, and is more than half way up the ridge

on which it is situated. The debris rushed down the side of the hill, which lies at an angle of 30° across the creek, up a neighbouring spur in a N.W. direction, for two hundred and fifty feet in a horizontal length and thirty feet vertical height, with such force that blocks of stone weighing over a hundredweight were carried up, the impetus being thus checked. The slurry was then diverted in a northerly direction back again into the creek; but this being soon choked up with debris, a fresh course was carved out by the moving mass. Large stringbark trees, broken off short, were spread about like spillekans about the ground, and large boulders were hurled along, carrying away fences in their course; the combined forces of debris throwing themselves against the dwelling-house of Mrs. Hershall, razed it to the ground, the sticks and stones covering acres of good land. The landslips that have taken place here may be classified into deep-seated and surface slips, and the latter into those that have quietly slid down, *en masse*, without disturbing the vegetation growing on them, and those broken up anyhow. Further, we may distinguish between those caused by water and those subsidiary ones due to their lower support having been removed. A series of these eat back into the hill, like a waterfall, scooping out a gully. The chief slip took took place in Mr. Robert Singleton's paddock, at the back of Mr. Sidney Ellery's residence, which stands on a spur, probably the remnant of a former slip. Several lesser slips took place at frequent intervals during the heavy rains, and still continue when there is much wet weather. On the E., and close to the main slip, are two minor ones. The foremost has dropped ten feet bodily, and so gently as not to disturb the large trees growing on it; that at the back being on steeper ground is more broken up. In these minor slips, which are mostly confined to the surface soil and a few floating boulders, the trees play a great part. Sometimes by falling they start a slip, but more frequently, by binding the earth together, they serve to retard the motion of the soil at the back of them, even in the case of the large slips. Trees are to be found growing erect on the edge of a precipice, which leads one to suppose that they have assisted in determining the line of slip. The slips invariably take a horseshoe form, as the rock breaking away at the weakest point drags away the land at its side, as it sinks down to form a terrace, leaving a natural quarry behind.

The country rock is diorite-porphyrite, consisting of a greenish grey felspar matrix thickly studded with crystals of oligoclase and, occasionally, blebs of quartz, flakes of magnesian mica, or crystals of hornblende, and containing iron pyrites as an accessory mineral; in fact, the varieties pass from plagioclase-porphyrite into mica and hornblende porphyrite, the whole weathering grey. The soil above this rock is reddish clay, two feet thick. Data to hand is not sufficient to enable us to judge what influence terrestrial movements, in the mountain building sense, has had in causing these slips, but it is evident that the main cause is due to the jointed nature of the rock enlarged in many places by roots of the vegetation growing on the surface, and wedged open by particles of earth falling in the crevices; water, with its gases, salts, and acids in solution, travelling along these natural water channels have attacked the felspathic minerals, forming clay and other

secondary minerals; these, while endeavouring to exfoliate, will also exert great force, and at the same time act as a lubricant to the blocks of stone. The cohesion of the rock being thus brought to the lowest possible pitch, it requires but the starting force to enable it to continue the motion down hill, the sides of which are too steep for the loose mass to rest on. The numerous cracks and joints collect an immense quantity of water, which, being dammed back by the clay, result in springs which are the sources of the creeks. Years of slow chemical action prepared the rock for its final dislodgment, the unusual pressure of water, owing to the great rains, soaked the ground and started the mass moving, the weight of the superincumbent material on an incline doing the rest, the more or less rotten boulders knocking up against one another provided the slurry and debris that has, for the time being, ruined some acres of lower lying land, the quantity of rotten rock showing the extent of decomposition the hill has been subject to. The land having been loosened and removed, its locality is drained, but where the water is stagnant evidences of chemical action are still to be seen in the ochreous deposits, the smell of sulphuretted hydrogen, and the iridescence on the surface of the pools due to minute crystals or iron pyrites.